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A review and new approach to minimize the cost of solar assisted absorption cooling system

V. Boopathi Raja [a,*], V. Shanmugam [b]

[a] Department of Mechanical Engineering, Narasu's Sarathy Institute of Technology, Salem 636305, Tamilnadu, India
[b] Sri Shanmugha College of Engineering and Technology, Sankari, Tamilnadu, India

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ABSTRACT

Solar energy is an alternative energy source for cooling systems where electricity is demand or expensive. Many solar assisted cooling systems have been installed in different countries for domestic purpose. Many researches are going on to achieve economical and efficient thermal systems when compared with conventional systems. This paper reviews the past efforts of solar assisted-single effect vapour absorption cooling system using LiBr–H_2O mixture for residential buildings. Solar assisted single-effect absorption cooling systems were capable of working in the driving temperature range of 70–100 °C. In this system LiBr–H_2O are the major working pairs and has a higher COP than any other working fluids. Besides the review of the past theoretical and experimental investigations of solar single effect absorption cooling systems, some new ideas were introduced to minimize the capital and operational cost, to reduce heat loss from generator and thus to increase COP to get effective cooling.

Contents

1. Introduction

Cold production through absorption cycles has been traditionally considered one of the most desirable applications for solar thermal energy. So, the most commercially developed solar cooling technologies are the absorption systems [1]. Conventional cold producing machines that are based on vapor compression principle are primary electricity consumers and their working fluids are being banned by international legislation. Solar powered cooling systems as a green cold production technology are the best alternative. Absorption refrigeration is a mature technology that has proved its applicability with the possibility to be driven by low

* Corresponding author. Tel.: +91 81 4425 9257; fax: +91 42 9024 9663.
E-mail address: boops.raja@gmail.com (V. Boopathi Raja).

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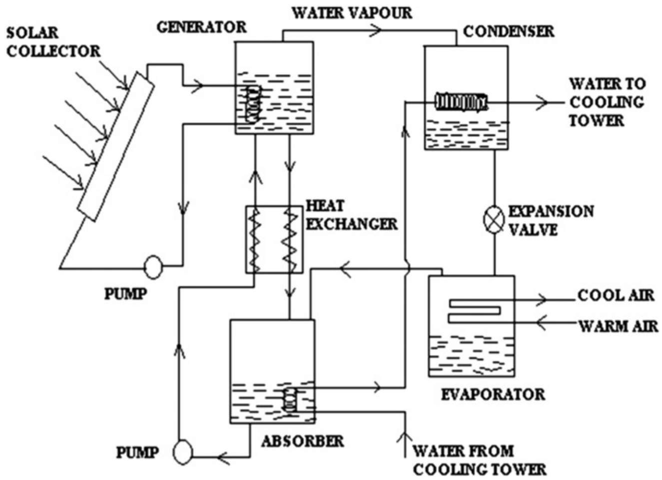

Fig. 1. Schematic representation of solar assisted single effect LiBr–H_2O absorption cycle.

grade solar and waste heat [2]. The CFCs and HCFCs gases, which are used by the conventional vapor compression cooling system have high global warming potential and also high ozone depleting potential. These effects can be remedied by choosing the environmental friendly cooling system like H_2O/LiBr absorption system. An advantage of this absorption system is that it can be driven by low grade thermal energy like solar energy [3]. An absorbent and a refrigerant in an absorption cycle form a working pair. The most common working pairs in absorption refrigeration are lithium bromide–water and water–ammonia. [4] For cooling purposes, the LiBr–H_2O system is the cheapest, while the cost of H_2O–NH_3 is high. The optimum generator temperatures in the LiBr–H_2O system for cooling purposes are around 75 to 92 °C. The lithium bromide–water pair is widely used for cooling applications, with evaporation temperatures about 5–10 °C.

1.1. Working principle of solar assisted lithium bromide–water absorption cycle

The basic working principle of solar assisted lithium bromide–water absorption cycle is depicted in Fig. 1, which is the simplest and most commonly used design. In the absorption cycle, compressing refrigerant vapour is achieved by the absorber, the solution pump and the generator. Water evaporated from evaporator (which outputs a cooling effect) is absorbed into a strong lithium bromide solution in the absorber, and the absorption process need to release heat of absorption to the ambient. After absorbing the water vapour, the lithium bromide solution becomes a weak solution, which is then pumped to the generator. As heat is added to the generator, water will be desorbed from the solution in a vapour form. The vapour then flows to the condenser, where it is condensed and condensing heat is rejected to the ambient. The condensed water flows through an expansion device, where the pressure is reduced. The strong solution from the generator flows back to the absorber to absorb water vapour again, a heat exchanger could be used between the strong solution and weak solution lines. The entire cycle operates below atmospheric pressure, since water is used as the refrigerant. The advantages of absorption method over conventional method is that they consume little electricity, they can be run by low thermal energy source, they have very few moving parts leading to low noise and vibration levels, and they do not emit ozone depleting substances [5].

Jaruwongwittaya et al. [6] pointed that the absorption cooling technology using lithium bromide/water was the most appropriate for the solar applications in Thailand. Fong et al. [7] compared five types of solar cooling systems for Hong Kong, the solar electric compression refrigeration, solar mechanical compression refrigeration, solar absorption refrigeration, solar adsorption refrigeration and solar solid desiccant cooling. Through this comparative study, it was found that solar electric compression refrigeration and solar absorption refrigeration had the highest energy saving potential in Hong Kong. Commercially available absorption chillers for air conditioning applications usually operate with solution of lithium bromide in water and use steam or hot water as the heat source [8]. According to the operating temperature range of driving thermal source, single-effect LiBr/H_2O absorption chillers have the advantage of being powered by ordinary flat-plate or evacuated tubular solar collectors. Under normal operation conditions, such machines need typically temperatures of the driving heat of 80–100 °C and achieve a COP of about 0.7. The hot water storage tank is used in the system as a heat reservoir. [9] For solar thermal cooling the cost of solar collection is much lower as a percentage of the overall cost, but the cost of the refrigeration system often represents a larger percentage of the cost. If the costs of refrigeration were to come down as well as thermal refrigeration COP increases, especially to values greater than 1, it could be expected that solar thermal cooling costs would be competitive with electric cooling costs. Solar thermal systems will be cost-competitive by 2030, if COP improvements and/or thermal collector costs comes down considerably. Dieter Boer et al. [10] states that the problem of satisfying a given cooling demand at minimum cost and environmental impact is formulated as a bi-criterion non-linear optimization problem that seeks to minimize the total cost of the cooling application and its contribution to global warming. The results obtained by them shows that with the current energy price and without considering government subsides on solar technologies, the use of solar energy in cooling applications is not economically appealing.

In this paper, the research works of solar-powered single effect absorption cooling systems were reviewed. Some new options were given for solar-powered single-effect absorption cooling systems for domestic purpose, economical comparison with vapour compression system was made and suggestions were given to reduce capital and operational cost.

2. Experimental investigations

There were some solar absorption cooling systems in large capacities up to several hundred kilowatts, the experimental investigations were mainly based upon medium and small-sized solar cooling systems. Usually, the cooling capacity and COP of solar cooling systems were tested under practical operating conditions. Rosiek and Batlles [11] reported the solar-powered single-effect absorption cooling system installed in the Solar Energy Research Center of Spain. According to the calculation, the cooling demand during the whole year was 13,255 kW h. The flat-plate solar collectors with the area of 160 m^2 and a single-effect absorption chiller with the cooling capacity of 70 kW were used to meet the energy demands for cooling in summer. The performance of the solar-powered cooling system was monitored and controlled by a control and data acquisition system. During one year of operation, it could be seen that the solar collectors were able to provide sufficient energy to supply the absorption chiller during the summer. The average values of COP and the cooling capacity were calculated for summer months, obtaining values of the order of 0.6 and 40 kW, respectively. Ortiz et al. [12] and Mammoli et al. [13] carried out the experiments of a solar cooling system for a 7000 m^2 educational building situated in a high-desert climate. There were two kinds of solar collectors in this system, which included 124 m^2 of flat-plate collectors and

108 m^2 of vacuum tubular collectors. A water–glycol mixture was pumped through the arrays and through a heat exchanger, which was connected to a hot water storage tank with approximate volume of 34 m^3. The absorption chiller was a Yazaki single-effect LiBr/H_2O water fired chiller. This 70 kW absorption chiller was designed to work with hot water supply temperatures in the range from 70 to 95 °C. The cold water produced by the absorption chiller is stored in seven 50 m^3 cold water tanks and supplied to the cooling coils. Large chilled water storage tanks were charged off-peak and discharged during the day, cooling the building in parallel with the chiller. According to the experimental results, in the peak of summer, the solar cooling system could supply approximately 18% of the total cooling load. This percentage could be increased to 36% by tuning the air handler operation and by improving the insulation in the storage tank.

Syed et al. [14] investigated a solar cooling system consisting of a 35 kW LiBr/H_2O absorption machine energized by 49.9 m^2 of flat-plate collectors. Thermal energy was stored in a 2 m^3 stratified hot water storage tank during hours of bright sunshine. The generator design of the machine allowed the use of hot water in the temperature range of 65–90 °C. The measured maximum instantaneous, daily average and period average COP were 0.60 (at maximum capacity), 0.42 and 0.34, respectively. The daily average collector efficiency (without considering pipe and plate heat exchanger losses) was 50%. Through the analysis of energy flows in the system, it was demonstrated that the technology worked best in dry and hot climatic conditions where large daily variations in relative humidity and dry bulb temperature prevailed. Praene et al. [15] presented a solar-powered 30 kW LiBr/H_2O single-effect absorption cooling system which was designed and installed at Institute Universitaire Technologique of Saint Pierre. It was reported that the solar loop could produce hot water to fire the absorption chiller from 8:00 a.m to 5:00 p.m. According to the first field test, the system was sufficient to obtain thermal comfort with the mean air temperature inside the classrooms of about 25 °C. Li and Sumathy [16] studied the performance of a solar-powered absorption air conditioning system with a partitioned hot water storage tank. The system employed a flat-plate collector array with the surface area of 38 m^2 to drive a LiBr/H_2O absorption chiller of 4.7 kW cooling capacity. The system was provided with a storage tank (2.75 m^3) which was partitioned into two parts. The upper part had a volume of about one-fourth of the entire tank. The study revealed that the solar cooling effect could be realized nearly 2 h earlier for the system operating in partitioned mode. In this system a solar COP of about 0.07, which was about 15% higher than with traditional whole-tank mode, was attained. Experimental results also showed that during cloudy days, the system could not provide a cooling effect, when operated conventionally, however in the partitioned mode-driven system the chiller could be energized, using solar energy as the only heat source.

Agyenim et al. [17] developed a domestic-scale prototype experimental solar cooling system, which consisted of a 12 m^2 vacuum tubular solar collector, a 4.5 kW LiBr/H_2O absorption chiller, a 1000 l cold storage tank and a 6 kW fan coil. The average COP of the system was 0.58. Experimental results proved the feasibility of the concept of cold store at this scale, with chilled water temperatures as low as 7.4 °C, demonstrating its potential use in cooling domestic scale buildings. The existing experimental results showed that solar-powered single-effect absorption cooling systems were capable of working in the driving temperature range of 70–100 °C. Generally, the system COP of about 0.6 could be obtained under the design condition. However, when a chiller worked at partial load, a low efficiency from solar to cooling would be obtained. Rodríguez Hidalgo et al. [18] developed an experimental facility with 50 m^2 flat-plate solar collectors. It fed a 35 kW single-effect LiBr/H_2O absorption machine. The chiller worked at partial load, during 2004 summer season for COP of 0.33. Izquierdo [19] conducted trials to determine the performance of a commercial 4.5-kW air-cooled, single effect LiBr/H_2O absorption chiller for residential use. Measurements were recorded over a 20-day period. The hot water inlet temperature in the generator varied throughout the day from 80 to 107 °C. The results for the period as a whole showed that cooling power tended to decline with rising outdoor dry bulb temperatures. At outdoor temperatures from 35 to 41.3 °C the chilled water outlet temperature in the evaporator climbed to over 15 °C. The total energy supplied to the generator came to 1085.5 kW h and the heat removed in the evaporator to 534.5 kW h. The average COP for the period as a whole was 0.49. Al-Dadah [20] conducted Propane miscibility tests in various lubricating oils and concluded that Propane is most miscible in Alkylated Benzene AB300 as compared to AB150 and shell Clavus oils 32 and 64. They used propane as refrigerant and alkylated benzene as absorbant and its performance was evaluated. The absorption system gave an effective cooling capacity of 1.3 kW. The COP increased with increasing generator temperature and by decreasing the absorber temperature. A COP was found up to 1.

3. Theoretical analysis and simulation

The main components of a solar absorption cooling system are the solar field, the absorption cooling system and the heat storage water tank. The overall system performances depend on the coupling of these three components. Such research works were carried out mainly by theoretical analysis and simulation with the aid of Simulation software like TRNSYS [21]. Balghouthi et al. [22] presented a research project aiming at assessing the feasibility of solar-powered absorption cooling technology under Tunisian conditions. The system was modeled using the TRNSYS and EES programs with a meteorological year data file containing the weather parameters of Tunis, the capital of Tunisia. The optimized system for a typical building of 150 m^2 was composed of a LiBr/H_2O absorption chiller of a capacity of 11 kW, a 30 m^2 flat-plate solar collector area tilted 35° from the horizontal and a 0.8 m^3 hot water storage tank. Florides et al. [23] designed a LiBr/H_2O absorption unit with the cooling capacity of 11 kW, which could cover the cooling load of a typical model house in Cyprus. The optimum system as obtained from the complete system simulations consisted of 15 m^2 compound parabolic collectors tilted at 30° from horizontal and a 600 l hot water storage tank. Assilzadeh et al. [24] reported a solar cooling system that had been designed for Malaysia and similar tropical regions using evacuated tubular solar collectors and a LiBr/H_2O absorption unit. It was shown that a 0.8 m^3 hot water storage tank was essential in order to achieve continuous operation and increase the reliability of the system. The optimum system for Malaysia's climate for a 3.5 kW system consisted of 35 m^2 evacuated tubular solar collector sloped at 20°. Atmaca and Yigit [25] simulated a solar cooling system based on a 10.5 kW constant cooling load. A modular computer program was developed for the absorption system to simulate various cycle configurations and solar energy parameters for Antalya, Turkey. It was shown that the solar collector area of 50 m^2, a 3750 kg storage tank mass seemed to be the best choice. Joudi and Abdul-Ghafour [26] developed an integrated program for the complete simulation of a solar cooling system with a LiBr/H_2O absorption chiller. The results obtained from the simulation were used to develop a general design procedure for solar cooling systems, presented in a graphical form called the cooling fchart. Using this design chart could simplify the designer's task for predicting the long term cooling energy supplied from a solar collector array

serving an absorption chilled water system. Besides, a correlation was developed from the simulation results for estimating the hot water storage size necessary for the solar cooling system. The coupling of the main components of a solar cooling system is determined by the cooling demand, solar resource availability, climatic conditions, component cost and component performance characteristics. The specific cooling capacity was observed to be 0.1–0.7 kW/m^2. Jian Sun [27] made a mathematical model of a single effect, LiBr–H2O absorption heat pump operated at steady conditions. He took into consideration of crosscurrent flow of fluids for heat and mass exchangers, two-dimensional distribution of temperature and concentration fields, local values of heat and mass transfer coefficients, thermal parameter dependent physical properties of working fluids and operation limits due to the danger of the LiBr aqueous solution hydrates and crystallization. It was found that the mass flux of vapor increased with the increase of absorber pressure, coolant flow rate, spray density of LiBr solution and decrease of coolant and input temperature of solution. And the vapor mass flux increased almost linearly with the increase of absorber pressure. Results derived from this model show agreement within 7% with experimental values. Xiaohong Liao [28] focused on the crystallization issues and control strategies in LiBr–H_2O air-cooled absorption chillers. He specified six causes which may trigger crystallization: (1) high ambient temperature; (2) low ambient temperature with full load; (3) air leak into the machine or non-absorbable gases produced during corrosion; (4) too much heat input to the desorber; (5) failed dilution after shutdown; and (6) chilled water supply temperature is set too low when the weather and/or exhaust are too hot. Bahador Bakhtiari [29] conducted an experimental and simulation analysis of a laboratory single-stage H_2O–LiBr absorption heat pump with a cooling capacity of 14 kW. Design characteristics of the machine was given and the temperature of chilled, cooling and hot water and, the flow rate of cooling water and hot water were found to be the most influential operating parameters. A design and dimensioning model of H_2O–LiBr absorption heat pumps was developed. The steady-state simulation results of the model were compared with experimental measurements.

4. New design options of solar-powered single-effect absorption cooling system

The schematic diagram of the proposed new design is shown in Fig. 2. As per the new design, three major electrical components are required to run the system. A fan in the air cooled condenser, a blower in the evaporator and a solution pump to pump weak solution from the absorber to the generator. In this new design the generator is placed inside the insulated hot water storage tank. This prevents heat loss from the generator to the surrounding. Also the insulation cost for the generator gets minimized. If the storage tank and generator are separate units then the hot water has to be circulated from the tank. As per the new design the generator is placed inside the tank, the heat transfer loss from the tank to generator is minimized. The hot water tank is located at the top of the collector, thermo siphon principle is used to transfer heat from the solar collector to the storage tank. This avoids the usage of pump to circulate the water from collector to tank. Thus the initial and operating cost of the VACS can be reduced. The two main circuits: 1. Hot water circuit (solar collector–hot water storage tank–solar collector). 2. Refrigerant circuit (generator–condenser–evaporator–absorber–solution pump–generator) is evacuated and the vacuum pressure can be raised to reduce the boiling point of water. This helps to run the absorption cooling system even in low solar thermal intensity. The refrigerant vapour and the strong solution from the generator are passed to the absorber by siphon principle and the components of the cooling system are placed at proper altitudes so that both fluids will flow in the required pressure. Zhaolin Gu [30] applied vacuum membrane distillation process in Li–Br absorption system. Hollow fiber module with polyvinylidene fluoride (PVDF) membrane material is used. This process has the advantages of lower temperature driving heater and enormous contact area per unit volume. This membrane can be used in the generator to operate at low temperature than traditional generator. The vapour absorption cooling system can also be integrated with components used in conventional cooling system to get better performance and reduce cost.

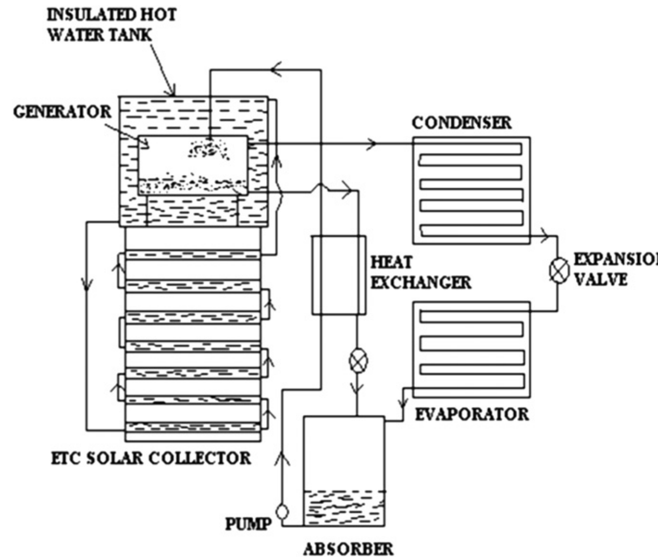

Fig. 2. New design with generator placed inside insulated hot water tank.

4.1. Solar collectors

Nearly all solar cooling systems were driven by ordinary flat plate or evacuated tubular solar collectors, which are available in the market. However, some new types of solar collectors have also been taken into account. Mazloumi et al. [31] simulated a single-effect absorption cooling system designed to supply the cooling load of a typical house in Ahwaz where the cooling load peak was about 17.5 kW. Solar energy was absorbed by a horizontal N–S parabolic trough collector and stored in an insulated thermal storage tank. It was concluded that the minimum required collector area was about 57.6 m^2, which could supply the cooling loads for the sunshine hours of the design day. The parabolic trough collectors obtained more solar heat energy in the areas with suitable direct radiation, which caused the cooling systems to operate earlier. Mittelman et al. [32] investigated the performance and cost of a CPVT system with single-effect absorption cooling. Concentrating photovoltaic (CPV) systems can operate at higher temperatures than flat-plate collectors. Collecting the rejected heat from a CPV system leads to a CPV/thermal (CPVT) system, providing both electricity and heat at medium rather than low temperatures. CPVT collectors may operate at temperatures above 100 °C, and the thermal energy can drive processes such as refrigeration, desalination and steam production. In the CPVT system, the thermal energy is a low cost byproduct and, therefore, could lead to a much more competitive solar cooling solution. The results showed that under a wide range of economic conditions, the combined solar cooling and power generation plant could be comparable to, and sometimes even significantly better than, the conventional alternative.

4.2. Auxiliary energy systems

For the purpose of all-weather operation, it is necessary to install auxiliary energy systems to supplement solar-powered cooling systems. Apart from electric heaters and oil boilers, almost all the auxiliary energy-to be used in case of scarce solar irradiation is supplied by a gas fired auxiliary boiler. The use of a gas-fired heater can be acceptable only when the auxiliary energy to be supplied is low [33]. Such a conclusion was also drawn by Calise et al. [34]. Compared with the auxiliary energy system of a gas-fired heater, the layout of an electric water-cooled chiller showed better energetic performance. It was showed that the primary energy saving of such a system vs. a traditional electric heat pump was close to 37%. In addition, the auxiliary energy systems for solar cooling systems could be used with other options of clean energy or renewable energy. Pongtornkulpanich et al. [35] designed a solar-driven 10-ton LiBr/H_2O single-effect absorption cooling system. It was shown that the 72 m^2 evacuated tube solar collector delivered a yearly average 81% of the thermal energy required by the chiller, with the remaining 19% generated by a LPG-fired backup heating unit. Prasartkaew and Kumar [36] presented a solar-biomass hybrid absorption cooling system which was suitable for residential applications. It consisted of three main parts: solar water heating with a storage tank, biomass gasifier fired hot water boiler, and single effect absorption chiller. The biomass gasifier hot water boiler was located between the hot water storage tank and absorption chiller machine. This insulated boiler had two functions: it worked as an auxiliary boiler when solar energy was not enough and worked as main heat source when the solar radiation was not available. Based upon the Bangkok meteorological data, the COP of the chiller and the overall system was found to be 0.7 and 0.55, respectively. Besides, the biomass (charcoal) consumption for 24 h operation was 24.44 kg/day. Ahmed Hamza et al. [37] reported the performance of an integrated cooling plant including both free cooling system and solar powered single-effect LiBr/H_2O absorption chiller, which had been in operation since August 2002 in Oberhausen, Germany. A floor space of 270 m^2 was air-conditioned by the plant. The plant included 35.17 kW cooling absorption chiller, vacuum tube collectors' aperture area of 108 m^2, hot water storage capacity of 6.8 m^3, cold water storage capacity of 1.5 m^3 and a 134 kW cooling tower. It was shown that free cooling in some cooling months could be up to 70% while it was about 25% during the 5 years period of the plant operation. For sunny clear sky days, collector's field efficiency ranged from 0.352 to 0.492 and chiller COP varied from 0.37 to 0.81, respectively. Li et al. [38] designed a 200 kW solar absorption cooling system assisted by a ground source heat pump (GSHP) with a rated cooling capacity of 391 kW. The chilled water produced by the solar cooling system was stored in a cold storage water tank. In order to maintain the setting temperature inside the cold storage water tank, the ground source heat pump was turned on either when the water temperature was higher than 18 °C or during the period from 22:00 to 7:00 with cheaper electricity tariff. As for a solar cooling system without any backup system, Marc et al. [39] indicated that it was very difficult to design this kind of installation and particularly to define the appropriate refrigerating capacity of the chiller. In a case where the chiller is undersized and runs in nominal conditions with good performances, thermal comfort inside the building will not be achieved in some critical periods of the year. In a second case where the chiller is oversized and does not run in nominal conditions with low performances, thermal comfort inside the building is achieved.

4.3. Cooling modes

Although the COP would be higher with a wet cooling tower, a dry cooling tower could be selected in order to avoid the usual problem of the legionella of the wet cooling towers. Monné et al. [40] reported a solar cooling system which consisted of 37.5 m^2 of flat-plate collectors, a 4.5 kW single-effect LiBr/H_2O absorption chiller and a dry cooling tower. The performance analysis of the solar driven chiller showed the average values of COP close to 0.6 in 2007 and between 0.46 and 0.56 in 2008. Concerning to the average cooling power, the chiller reached values between 4.0 and 5.6 kW in 2007 and between 3.6 and 5.3 kW in 2008. The studies indicated the great influence of the temperature of the heat rejection sink on the machine performance. Helm et al. [41] suggested that a low temperature latent heat storage together with a dry air cooler in solar-driven absorption cooling systems was a promising alternative to a conventional wet cooling tower. The reject heat of the absorption chiller was buffered by the heat storage and transferred to the ambient during periods of low ambient temperatures, e.g., night time or off-peak situations. An analysis of the thermal design of the different system components showed that latent heat storage allowed for moderate temperatures of the driving heat and thus substantially reduced the over-sizing of the solar collector system. In this study, the phase-change material (PCM) calcium chloride hexahydrate with phase transition, i.e., melting and solidification, in the temperature range of 27–29 °C was applied. The latent heat storage provided a 10 times higher volumetric storage density in comparison to a conventional water heat storage. By means of a latent heat storage integrated into the heat rejection loop of the chiller, a part of the auxiliary power demand can be shifted to off-peak hours with only a marginal increase of the overall electric consumption of the solar cooling system. As a consequence, a reduction of the operating cost is accomplished due to the reduced night tariff for electricity. And for the operation of the electric grid, a more even load profile with reduced daytime peaks is achieved, allowing for increased efficiency and reduced cost in power generation [42].

4.4. Formulae for the calculation of various parameters

The instantaneous values of solar thermal plant during the day were found from Eqs. (1)–(3).

$$Q_t = A_{col} \times Gt \tag{1}$$

$$Q_{col} = m_{fcol} Cp_{fcol}(t_{ocol} - t_{icol}) \tag{2}$$

$$Q_{\mathrm{itan}\ k} = m \times Cp(t_{\mathrm{otan}\ k} - t_{\mathrm{itan}\ k}) \tag{3}$$

The collector efficiency (η_{col}) calculated from Eq. (4).

$$\eta_{col} = Q_{col}/Q_t \tag{4}$$

The heat transfer rate of generator (Q_g), evaporator (Q_e), absorber and condenser (Q_{a+c}) are calculated from Eqs. (5)–(7).

$$Q_g = m \times Cp(t_{ig} - t_{og}) \tag{5}$$

$$Q_e = m_{chill} Cp_w(t_{ie} - t_{oe}) \tag{6}$$

$$Q_{a+c} = m_{air}(t_{0air} - t_{0db}) \tag{7}$$

The thermal, electric and primary energy COPs, calculated from Eqs. (8)–(10).

$$\mathrm{COP_{th}} = Q_e/Q_g \tag{8}$$

$$\mathrm{COP}_{elec} = Q_e/W_{elec-prot} \tag{9}$$

$$\mathrm{COP_{prime\ energy}} = Q_e/Q_g + (W_{elec-prot}/\eta_{conv}) \tag{10}$$

The Solar facility performance (SFP) and solar coefficient of performance (SCOP) were calculated from Eqs. (11) and (12).

$$\mathrm{SFP} = Q_g/Q_t \tag{11}$$

$$\mathrm{SCOP} = Q_e/Q_t \tag{12}$$

5. Economical comparison

Analysis of overall initial and operating costs and comparisons of alternatives require an understanding of the cost, the comfort demands and the environmental impacts of the system. According to Al-Daini [43] there are two main methods to compare the cost of any two or more systems.1. First Cost comparison. It reflects only the initial price, installed and ready to operate, and ignores such factors as expected life, ease of maintenance and even, to some extent, efficiency. 2. Life-Cycle Cost (LCC), which includes all cost factors (first cost, operating cost, maintenance, replacement and estimated energy use) and can be used to evaluate the total cost of the system over the complete life of the system.

A comparison of general cost associated with single effect vapour absorption and vapour compression air-conditioning system is made. The cost analysis covers the initial costs and the operating costs of each of the systems. The selection depends on which system requires the minimum life-cycle cost (LCC) and can perform the intended function for its life span.

5.1. Initial costs

The initial costs for the single-effect solar vapour absorption systems include the absorption machine, heat rejection equipment, and solar energy collection system. The physical size of the absorption system is larger than the size of the vapour compression system; this increase in size requires a larger building, moving equipment and support systems. This results in a higher installation cost for the vapour absorption system. The initial cost therefore should include, in addition to the purchase and installation of the systems, the various subsystems necessary for effective operation. This includes piping, wiring and specific structures. The solar energy collection system plays the most significant role in the initial cost of the vapour absorption system.

5.2. Operating costs

Operating costs, which include the costs of electricity, wages of employees, supplies, water and materials, are those incurred by the actual operation of the system. With regard to the vapour compression system, the operating costs are dominated by the electricity required to drive the compressor. Additional electricity is used to drive the condenser water pump and the cooling tower fans.

5.3. Maintenance costs

There are various levels of maintenance that may be applied to building air conditioning services. The three most common levels are run-to-failure, preventive, and finally predictive maintenance. The maintenance cost is difficult to quantify because it depends on a large number of variables such as local labour rates, their experience, the age of the system, length of time of operation, etc. The maintenance cost for the heat rejection subsystem tends to be higher for the VAS due to more rapid scaling; however, this could be offset by the maintenance cost of the VCS because it is a work-operated cycle. Maintenance costs cited in various studies show that the vapour absorption system's maintenance costs range from 0.6 to 1.25 times the maintenance costs of the vapour compression system.

6. Conclusion and suggestions

It is concluded that single effect absorption cooling method using LiBr–H_2O as working fluid pair is more suitable for domestic purpose. Flat plate and evacuated tube solar collectors are more reliable and economical for this system. It is found that two important parameters determine the most economical solar cooling system. They are: 1. the cost of the solar collection and storage technologies 2. the performance of the cooling technologies. By considering the two parameters some suggestions were given as follows: (i) By placing hot water storage tank above the solar collector and thermo siphon principle can be used for transferring the heat from collector to tank (ii) Heat loss due to transfer of hot water from storage tank to generator can be avoided by placing the generator inside the insulated storage tank. Also the insulation cost for the generator can be minimized (iii) The vacuum pressure of the cooling circuit can be increased to enhance the boiling of water inside the generator (iv) According to the new idea given in this paper only three major electrical equipments are used (condenser fan, cooling coil fan and a pump). Hence the operational cost is very much minimized when compared with compression system. Though the initial cost is more, there are many possibilities for reducing the operational cost of the solar cooling system. Hence finally it is indicated that solar assisted single effect absorption cooling system would be competitive with compression cooling system when compared for long term operation.

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